3.9 GEOLOGY, SOILS, AND SEISMICITY

The Hawaiian Islands formed as the Pacific Plate moved over a relatively permanent hot spot in the mantle beneath the plate. The long chain of islands that stretch for hundreds of miles are the result of thousands of years of slow movement of the Pacific Plate and sea floor eruptions. Due to the composition of the oceanic crust, which differs from the crust that forms the continents, eruptions of Hawaiian volcanoes are generally not explosive or violent.

The sedimentary rocks of O'ahu include both terrestrial and marine deposits. A wedge of stratified marine sedimentary deposits interbedded with volcanic rocks, known as caprock, overlies the coastal plain at the north and south ends of O'ahu. The caprock is relatively impermeable and confines groundwater in the basal aquifer system below it.

Soil types present in the islands vary greatly because of local climate, slope, drainage and age of island. There are twelve soil "orders" in modern soil classification and eleven of these are present in the Hawaiian islands. _The bountiful arable soils of the islands have allowed the success of both commercial and subsistence agricultural practices.

The Hawaiian Islands are affected by earthquakes. One cause of earthquakes is the movement of molten rock as it rises through fractures in the earth's crust. The other cause of Hawaiian earthquakes is settlement of the upper part of the earth's crust under the weight of accumulated lava. This settlement accumulates over millions of years, but may occur suddenly.

3.9.1 Introduction/Region of Influence

The ROI for geologic impacts of the project is all areas in which project-related activities may occur, including the footprint of each training and construction area and the corridors of the military vehicle roads. It also includes adjacent areas that may be affected by geologic processes in the project area. An example would be downslope areas adjacent to a roadcut or embankment that might be affected by slope failure.

3.9.2 Resource Overview

Physiography

Geologic Origin of the Hawaiian Islands

The Hawaiian Islands are located near the center of the Pacific Plate, one of many oceanic crustal plates that form the surface of the earth beneath the oceans. The Hawaiian Islands formed as the Pacific Plate moved slowly northwestward over a relatively permanent hot spot in the mantle beneath the Pacific Plate. The hot spot melted the oceanic crust above it, causing the melted rock (magma) to rise through the crust and ooze out slowly onto the ocean floor, eventually piling high enough to emerge above the surface of the ocean and form islands. The hot spot is currently beneath the island of Hawai'i, but four million years ago it was beneath O'ahu (Hazlett and Hyndman 1996). The long chain of islands that stretch for hundreds of miles to the northwest of O'ahu attest to the fact that the Pacific Plate has been moving slowly over the hot spot for many millions of years. The hot spot is relatively small, and as the Pacific Plate passes over it, the once-active volcanoes cool and stop erupting. Over time, the volcanic peaks are worn down to near sea level by erosional processes, leaving shallow platforms on which coral atolls (a ring of coral reefs that form a lagoon) can grow.

Due to the composition of the oceanic crust, which differs from the crust that forms the continents, eruptions of Hawaiian volcanoes are generally not explosive or violent. The vast bulk of Hawaiian lavas tend to be hot and thin, enabling them to flow rapidly in thin layers, and to gradually build up huge, gentle-sloping domes called shield volcanoes. The texture of the lava varies, depending on differences in rate of flow and cooling, on distance from the vent, and on whether it is deposited on land or under water. As a result, the lava may be highly fractured and blocky (called ʻaʻā lava) or dense, smooth or ropy, and unfractured (pāhoehoe). Sometimes the lava in the center of a flow continues to flow after the outer surfaces have cooled and hardened, leaving a hollow tube. Lava tubes can eventually become conduits of surface water or groundwater.

Over time the composition of the magma changes. More explosive eruptions tend to occur near the end of the eruptive history of an island. More gaseous, explosive lavas result in cinder cones and deposits of cinders and ash. Thus, in a sequence of lava flows deposited over thousands of years, there may be many variations in the texture and permeability of the rock.

Hawaiian volcanoes tend to erupt along rift zones, which are linear zones of fractures through which magma moves upward from a magma chamber deep in the crust where melting occurs. After erupting, some of the magma remains to fill the fractures, creating vertical sheets of rock called dikes that crosscut the horizontal layers. The dikes tend to be denser and harder than the lava that is deposited above the surface, and they are more resistant to erosion later. The dikes also influence groundwater movement.

Eruptive episodes may occur decades or even thousands of years apart from different active vents, and the lava flows may follow different routes over time. These variations allow weathering processes time to break down the lava and form soil. Lava that weathers in place is called saprolite, and sequences of saprolite tens of feet thick can occur.

The sedimentary rocks of Oʻahu include both terrestrial and marine deposits. Sedimentary rocks can be classified as either containing large amounts of calcium carbonate (calcareous deposits) or as noncalcareous. Many calcareous deposits are highly permeable. Reef limestone, coralline rubble, and calcareous sand comprising the upper sedimentary layers in coastal areas tend to make highly productive, permeable aquifers. A wedge of stratified marine sedimentary deposits mixed with and interbedded with volcanic rocks, known as caprock, overlies the coastal plain at the north and south ends of Oʻahu. The caprock is relatively impermeable and confines groundwater in the basal aquifer system below it.

Terrestrial sedimentary deposits consist of alluvium deposited by streams, rock material deposited at the foot of steep slopes, and mixed erosional deposits called colluvium. Alluvium derived from weathering of basalt tends to be clayey and low in permeability, and the rapid deposition of sediments eroded from short steep watersheds tends to prevent sorting and winnowing of sands and the formation of identifiable layers. Instead, the deposits become mixed.

The volcanic deposits contain many fractures and tend to be quite permeable. However, they also tend to weather rapidly and deeply from exposure to rain, groundwater, and vegetation. The weathering may continue long after the deposits have been buried beneath other deposits. As a result, the rock may weather in place without being eroded. The original minerals in the rock become altered to iron-rich clay minerals, while retaining much of the appearance and structure of the original rock. The result is an altered rock with soil-like properties called saprolite.

Island of Hawai'i

The island of Hawai'i is the youngest of the Hawaiian Islands and is the only island that is still growing. Therefore, the landscape is younger and less affected by erosion than other islands. Also, the island is larger and higher than the other islands. The bulk of the island of Hawai'i was formed from the eruptions of five shield volcanoes. Kohala, the oldest, is extinct. Mauna Kea last erupted about 3,500 years ago and is considered dormant. Hualālai last erupted in 1801. Mauna Loa and Kīlauea are both active.

Island of O'ahu

O'ahu was formed from two eruptive centers, shown on Figure 3-11 as the Ko'olau and Wai'anae calderas. The remnants of the oldest, the Wai'anae Volcano, forms the Wai'anae Range on the eastern side of the island. The highest peak in the Wai'anae Range, Mount Ka'ala, is south of the Mākua Military Reservation and rises to an elevation of 4,025 feet (1,227 meters) above mean sea level (msl). About 3 million years ago, the western and northern flanks of the Wai'anae Volcano slumped into the ocean in two sudden and catastrophic events. The south side of the Wai'anae Volcano eroded rapidly, forming the Lualualei Valley. Erosion also stripped the young deposits from the north and east flanks of the volcano and deposited them in the adjacent valleys.

The oldest basalts, which form the bulk of the Wai'anae Volcano, are thin flows of pāhoehoe lava lying at relatively low angles to horizontal. These are known as the Lualualei member of the Wai'anae formation. Later lavas, which were thicker, contained more silica, and were more restricted to the caldera, belong to the Kamaile'unu member of the Wai'anae formation.

The Wai'anae Volcano contained a large crater, or caldera, about 4.5 miles (7.2 kilometers) across that was crossed by two narrow rifts zones that extended northwest and southeast. The rift zones are filled with vertical dikes representing the locations at which magma moved upward before erupting. The resistant rock of the dikes in these rift zones now forms the ridges of the Wai'anae Range. Additional dikes radiate outward from the volcano (Hazlett and Hyndman 1996). The western slope of the Wai'anae Volcano slumped into the Hawaiian deep in a massive landslide that extended up to 50 miles (80 kilometers) across the ocean

Figure 3-11
Generalized Geology on O'ahu

floor. A slump of the north side of the volcano, called the Ka'ena Slide, spread debris about 70 miles (113 kilometers) and created an escarpment parallel to the north shore between Ka'ena Point and Waialua.

A third member, the Kolekole member, represents material erupted from cinder and splatter cones on the southeastern flank of the volcano until about 2.75 million years ago, when the Wai'anae Volcano became extinct.

At about this time, the Ko'olau Volcano, which had been forming to the east of the Wai'anae Volcano, began to emerge above sea level. As with the Wai'anae Volcano, two rift zones developed, trending to the northwest and the southeast, respectively. As the Ko'olau Volcano emerged, the saddle between the two volcanoes was filled mainly with sediments eroded from the Wai'anae Volcano. Later, it was overlain by basalt flows from the Ko'olau Volcano. As the Ko'olau Volcano waned, the saddle area was buried under alluvium from erosion of the Ko'olau Volcano. Thus, the saddle area is underlain by alternating basalt flows and alluvial deposits.

The Ko'olau Volcano accounts for about two-thirds of O'ahu. About 2 million years ago, the eastern slope of the volcano slumped into the Hawaiian Deep in a massive slide that created a swathe 20 miles (32 kilometers) wide and deposited material miles (193 kilometers) to the northeast. The event is known as the Nu'uanu Slide. The eruptive 120 period of the Ko'olau Volcano ended about 1.8 million years ago. It was followed by deep erosion of the volcano's caldera, thousands of feet of subsidence, and beginning about 850,000 years ago, the first eruptions of the Honolulu basalts.

Eruptions of the Honolulu basalts began on the Mōkapu Peninsula near the north side of the Ko'olau caldera, and then continued to the south to Lē'ahi (Diamond Head), and west to Pearl Harbor. About 40 eruptions occurred in the period from 850,000 years to 6,000 years ago.

The last period of active volcanism on O'ahu ended about 6,000 years ago. However, it has been pointed out that the quiet periods between volcanic events during the past 800,000 years have often exceeded 6,000 years, so it is not known for certain that eruptions will not occur again in the future.

Seismicity

The Hawaiian Islands are affected by earthquakes resulting from two causes. One cause of earthquakes is the movement of magma (molten rock) as it rises and intrudes fractures in the crust in volcanic eruptions or in advance of those eruptions. Volcanism on O'ahu is no longer active, but earthquakes of this type could result from activity in the vicinity of the island of Hawai'i.

The other cause of Hawaiian earthquakes is settlement of the lithosphere (the upper part of the earth's crust) under the weight of the accumulated lava that has erupted from the Hawaiian volcanoes. This settlement occurs over millions of years, but it occurs in sudden episodes. O'ahu is one of the most stable in this respect. However, lithospheric settlement of the islands of Hawai‘i, Lana‘i, and Maui has resulted in a number of large earthquakes (greater than magnitude 6) during the past 150 years. An earthquake estimated to have been magnitude 6.8, centered beneath Lana‘i in 1871, caused extensive damage in Honolulu (USARHAW and 25th ID[L] 2001a). O‘ahu is no longer subsiding and now has the most stable elevation in the Hawaiian Island chain.

The US Geological Survey National Seismic Hazard Mapping Project has prepared maps showing the magnitude of ground shaking events for specific probabilities of exceedance in a given period of time throughout the Hawaiian Islands (Klein et al. 2001). These maps indicate that the likely intensity of ground shaking decreases with distance from the south coast of the island of Hawai‘i, which is the area of most current earthquake activity. O‘ahu is in an area in which there is a 10 percent chance that ground accelerations of 10 to 12 percent of the acceleration of gravity will occur in the next 50 years. Earth materials vary in their response to seismic waves; firm rock tends to move the least, while loose unconsolidated materials shake more in a given earthquake. The ground acceleration probability estimates provided by the US Geological Survey apply to firm rock conditions.